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L. HARRISON METTLER, A.M., M.D.

CHICAGO, ILL.

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THE SENSORY-MOTOR FUNCTIONS OF THE BRAIN.

THERE seem to be nationalities in science as well as in statecraft. In a general way it may be said that the English-speaking physiologists regard the sensory and motor areas of the brain as separate and distinct, and that they look upon them as the centres for the direct reception and emission of sensory and motor impulses. The Germans favor the view that these areas are the centres for the direct reception and emission of nervous impulses, but they hold that they coincide or are more or less intermingled. The French and Italian investigators study the question more from the psychological standpoint, and place less stress upon the separation or commingling of the sensori-motor areas than they do upon the doctrine that the cortex is a general centre for the representation of motor and sensory images. Psychosis, according to them, is a sensori-motor phenomenon, and mentalization the result of the combined activities of the cortical sensory and motor areas. The direct sensori-motor elements are lower down than the cortex. Impulses of cerebral origin are as much peripheral as those starting from the skin. Voluntary action is as much a reflex as an ordinary involuntary spinal reflex. This is a mere outline statement of the three theories now in vogue in regard to the sensori-motor areas of the basin. For the doctrines of the Italian school I must acknowledge my indebtedness to the work of M. Jules Soury, "Les Fonctions du Cerveau," whose account I have made ample use of. The teachings of the English and German

physiologists are more familiar than those of the Italians to the average American reader. The views which I will venture to advance in the latter part of this essay tend somewhat, though not entirely, toward the Italian doctrines.

It is much to be regretted that patients presenting symptoms of a lesion in the motor zone of the cortex are not more frequently and minutely examined with regard to general sensation. In many of the reported cases of paralysis there is no mention whatever of sensation; and in others, where the attempt has been made to discover the sensibility of the skin, the methods adopted have been so crude and unscientific, and the results obtained so meagre and indefinite, that the report, in this respect at least, is almost valueless. In comparison with the motor tests for the localization of a cortical lesion, sensory tests will probably always remain less popular. The variation of the personal equation alone is enough to shake one's reliance on sensory symptoms, and to properly perform these tests necessitates an unusual amount of patience, shrewdness, and insight into human nature. The instruments of precision must be employed in every conceivable manner, and frequently at most unexpected moments. Unlike the testing for paralysis, we are here dependent almost absolutely upon the patient and his subjective feelings; hence we must study closely the patient's peculiar temperament and make due allowances for his intellectual status. His entire physical condition must at the same time be taken into consideration, for if there be paresis, for instance, a sensory response may be very greatly modified by the inability of the muscles to act and manifest the appropriate motor response. Notwithstanding all these difficulties it is extremely desirable that every case of paralysis be carefully and accurately tested for general sensation. The experiments of the laboratory favor the view that the sensory areas of the cortex are separate and distinct from the motor, while clinico-pathological data intimate that they are identical, or at least partly coinci-

dent. Which is the true condition can only be settled by the most rigid physiological and pathological observation.

In regard to the centres for cutaneous sensations—touch, pain, temperature, and the sensation commonly known as the "muscular sense"—many theories have been advanced. The general consensus of opinion holds that the optic thalamus is the basal ganglion for the reception of sensory impulses from the outer world. Luys, Ferrier, von Monakow, Fournier, and Crichton-Brown so teach; though Flourens, Longet, Tamburini, and Schiff attribute motor functions to this ganglion. Above the thalamus the fibres radiate through the corona and terminate chiefly in the cortex of the parietal and temporo-sphenoidal lobes. Below the thalamus the sensory are clearly distinguishable from the motor paths. Do these so unite or intermingle above this ganglion as to terminate in the same cortical area, or do they still remain apart, one set (motor) going to the central lobes, the other set (sensory) turning back to end in the postero-parietal lobes?

In his earlier experiments Ferrier found that injury to the hippocampal convolution and cornu ammonis produced loss of tactile sensibility on the opposite side of the body. He therefore located the centre for tactile sensibility in the region of the hippocampus. This was confirmed by Yeo in his experiments on monkeys in 1884. Horsley and Schäfer have extended the views of Ferrier, and as a result of their investigations concluded that the whole of the limbic lobe (including the callosal and hippocampal regions) presided over the sensations of touch and pain, if not exclusively, at least to a very large extent. In some of their experiments the loss of sensation was accompanied by motor phenomena, which they attributed to unintentional injury of the motor area during the performance of the operation. As opposed to Munk and Schiff, who would possibly argue from this the identity, in part at least, of the motor and sensory areas, they

state that in some of their experiments there was paresis of the lower limbs with anæsthesia of the upper limbs, and in others anæsthesia without paralysis.

There seems to be some very intimate connection between the limbic lobe and central lobules, for when we remember how frequently sensory auræ and other paræsthesiæ precede and accompany Jacksonian symptoms caused by a limited lesion of the motor cortex, we must admit, if not the identity, at least the extreme intimacy of the motor and sensory areas. Many of these focal lesions do not extend deep enough to involve the radiating fibres from the sensory areas, and their mutual influence must, therefore, be entirely cellular and transmitted from one to the other by associating fibres.

This influence may be of an inhibitory nature, for clinically the anæsthesia accompanying such forms of local paralysis is never complete, but is rather of the inhibitory type. Brown-Séquard has given special attention to the extensive inhibitory functions of the nervous system, and in the light of his investigations such an explanation is not unwarrantable. If the sensory and motor areas were identical, it is hard to comprehend how a limited focal lesion could give rise to complete paralysis and incomplete anæsthesia in related parts of the body. Both sets of cortical cells would, presumably, be similarly injured, and the anæsthesia would be more or less proportionate to the amount of paralysis. Ferrier's objection to the experiments of Munk and his followers, in this connection, seems to me to be a weak one when he states that in animals the loss of sensation is only apparent and not real, because the paralyzed animal is unable to express any sensation. This may do for animals, but in man there is an abundance of clinical observation which goes to show that there is frequent loss of sensation with Jacksonian symptoms.

The sensorial area is thus made to include the gyrus fornicatus, hippocampal convolution, procuneus, and portions of the parietal convolutions. In a general way it

may be stated as the postero-parietal parts of the hemispheres. This arrangement seems to be established by pathological observations in man, as well as by experimental investigations upon the lower animals. It must not be forgotten, however, that Ferrier's observations were made mostly upon the lower animals, and that the focal epilepsies, which finally terminate in general convulsions, reveal a higher and more intricate structure of the human brain.

Those who maintain that the histological structure of the central convolutions affords a clue to their proper functions reason beyond the facts. Thus Gowers says "it is instructive to note that in this part are found the largest ganglion cells met with in the cortex, cells comparable to, though exceeding in size, the certainly motor-cells of the anterior cornu of the spinal cord." Nevertheless we find in the histological structure of the hippocampal convolution, which is admittedly sensory in function, pyramidal cells very similar to those of the motor areas. They lie just beyond what is known as the stratum radiatum. Furthermore, these large cells have never yet been proved to be strictly motor. They may be muscular, meaning by that term that they are in immediate connection with the muscular apparatus, and are therefore capable of a grosser or more vigorous form of activity than the delicate receptive sensory cells. But when we remember that sensation itself is but a mode of motion we can understand that these giant-cells may differ from the smaller ones not so much in kind as in degree. The reflex character of most of the sensori-motor phenomena would seem to indicate that both sets of cells possessed the faculty of receiving and emitting nervous impulses and it is hard to escape the conclusion that the real differences in their functions are dependent more upon the nature of the terminal end-organs, with which they are connected, than upon their own particular structure. Physicists believe that all phenomena are but the expression of a form of motion. Light, heat,

electricity, are but different modes of molecular motion. Nervous activity has often been likened to electricity; but whether the comparison be true or not, it is more than probable that the former is as much a mode of motion as the latter. Both sensory and motor phenomena are alike the result of molecular movements. The muscular contractions are doubtless the direct expression of the molecular changes within the muscular tissues and the reflex circle, beginning in a peripheral irritation, running through the centre from sensory to motor cells, and finally passing out again to terminate in gross muscular contractions, is simply the transmission of the same molecular disturbance, differing in degree, but not in kind, in the various parts of the arc. In a rough way it may be compared to a taut string which experiences throughout its entire curve a gentle vibration started at either extremity.

The most positive knowledge we possess in regard to the functions of the cortex is that the central convolutions somehow preside over the movements of the body. And yet, as Gowers says, "we need not conceive that these parts subserve no other function (we shall presently see reason for believing that they have sensory as well as motor functions)." Injury to these convolutions produces spasm or paralysis, and, so far as we know, these symptoms are not produced by cortical lesions outside of these convolutions and their immediate neighborhood. That these are not the only centres that preside over voluntary motion is to be inferred from many experiments upon animals. A rabbit whose entire cerebrum has been removed can still run; and, according to Goltz,[1] there was no complete paralysis, but only a slight anæsthesia, observed in a dog whose whole brain except one occipito-parietal lobe was excised.

It is an old-established fact that removal of the cerebral hemispheres, olfactory ganglia, optic lobes, corpora striata, and optic thalami does not result in the loss of

[1] Arch. für die gesammte Physiologie, Bd. 42.

voluntary motion and general sensibility. There is loss of intelligence, of inhibitory rationality; but the animal still executes purposive movements which are quite different from the simple reflex acts depending upon the spinal cord. Hence the question arises, What is the nature of these disturbances of voluntary motion caused by destruction of the cortical motor areas? A dog deprived of his two sigmoid gyri does not manifest motor paralysis, if by that term is meant absolute loss of motility. There is not a single physiologist who maintains such a thesis; hence the ground for the criticisms of Goltz, the distinguished opponent of the localization theories. The cortical motor areas must therefore preside in some special way over the muscular apparatus, and not directly, as at first seemed to be the case. In 1876 Hitzig spoke of the effects of cortical lesions in the motor area as "the expression of an abnormal representative action;" in other words, as the result of a destruction of the motor images belonging to certain voluntary movements. The muscles of the animal are not paralyzed, but the animal no longer possesses any mental images or ideal representations of the movements it should make or desires to make. The condition is probably somewhat like that of the nightmare, in which the sufferer is more or less conscious of his surroundings and is full of a desire to move, but is incapable of action, or acts only automatically.

Nothnagel and Bastian favor the theory of Hitzig, but they differ in locating a centre for the "muscular sense" outside of the central lobules. The former declared to the Sixth Congress for Internal Medicine, held at Wiesbaden, that he had never known focal lesions of the motor zone to produce loss of muscular sense, but that such lesions were often accompanied by a loss of tactile sensibility. He places the sensory area in the parietal lobes, where he also locates, together with Seguin, the special centre for the muscular sense—a sense which Mills sees no reason for separating from that of general sensation.

Nothnagel further states that the parietal lobes bear the same relation to the central and paracentral lobules that the convolution of Broca bears to the cortical hypoglossal motor centre. Injury to the parietal centres may produce ataxia without true paralysis, and injury to the central areas may produce paralysis without the loss of the muscular sense. This is somewhat of a return to the limitation views of Ferrier, and, in fact, both Nothnagel and Charcot separate the motor areas from the centres of cutaneous and muscular sensibility. For Charcot, however, the cortical motor centres are the seat of motor representations or conceptions, which must necessarily precede the accomplishment of any voluntary movement, while the muscular sense, or kinesthesic sensibility of Bastian, is subserved by the cortical centres of sensation.

According to Schiff, the so-called motor areas are entirely sensory, their activity is largely of the nature of a reflex, and the paralysis due to their injury is really the result of the loss of tactile sensibility. Munk does not believe that these centres determine movements directly, or in any reflex manner, but merely by the awakening of the mental images or representations of both general sensibility and motility. These ideational centres are not in immediate connection with the individual muscles, nor do they exert their influence directly for their individual actions. As Dr. Theodore W. Fisher [1] has tersely put it, "the will can only control and the mind is only conscious of movement in the mass." The fact that stimulation of certain areas of the cortex produces movement of groups of muscles and the co-ordinated movements of the segments of the limbs, shows that movements and not muscles are represented in the cortex. Many of the opponents of Ferrier's views have lost sight of this fact because this investigator insisted so strenuously upon the anatomical distinction and separation of the sensory and motor areas, and upon the sharp limitation of the latter

[1] Cerebral Localization, American Journal of Insanity, October, 1889.

to the central lobes. Munk's theory is popular in Germany, and makes the so-called motor areas entirely sensory. The activity of these centres results in "conceptions of movements," rather than the movements themselves. They are the psychical origin of the impulses which farther down the tract (possibly in the basal ganglia or anterior cornua of the cord) are transformed into the true motor stimuli that set the muscles into action. The cortical motor area is named by Munk, therefore, the "Sense-sphere" (Fuhlsphäre). Gowers' objection to this theory is that the "sense of innervation," an element of the threefold "conception of movement," is a sense of something which is not itself sensory, and which is commonly termed motor, and that destruction of this region causes loss of this "motor" function out of all proportion to any demonstrable sensory loss. The first of these objections seems weak to me; for it is a fact, as Stricker and others have demonstrated, that movements are preceded by psychical representations, which representations must obviously be of a sensory character. Franck inclines to the theory of a reflex action in the motor areas. He believes that the motor, like the sensory zones, are only the points of departure for voluntary motor impulses, while the true motor apparatus, or executive centres, are to be found in the cellular elements of the medulla and spinal cord. All of the cortical areas, according to this author, are merely centres of voluntary association. We know that the sensory and motor elements of the cortex are united by associating fibres, just as they must undoubtedly be lower down in the cord to complete the reflex arcs. The reflex phenomenon, both spinal and cerebral, necessarily presupposes such a union of the sensory and motor elements. This, it seems to me, can explain most plausibly the occasional association of the two sets of symptoms when the lesion happens to be limited to one or the other area. Such an assumption is not unwarrantable upon any anatomical or physiological basis, and it harmonizes most

completely with the results of experimental and clinico-pathological observation—certainly more so than does the assumption that the motor and sensory areas coincide or consist of the same cellular elements.

Formerly all reflex functions were supposed to belong exclusively to the spinal cord, but to-day we consider the cerebral centres as much reflex as the spinal. Many of the Jacksonian epilepsies are undoubtedly of simple reflex origin. Mills[1] reported in 1880 a case, clearly Jacksonian in type, that had had seizures for eleven years, caused by a fibroma in the hand. When the tumor was removed the epileptic seizures eventually disappeared. "In the normal brain," Mills writes, "no reflex actions can be performed without exciting to action secondary volitional movements which no longer require the stimulating influence of a reflex action." The absence of gross cortical lesions in some forms of Jacksonian epilepsy, and Heidenhain's experiments in hypnotism, with other observations and facts, all prove conclusively the reflex function of the cortical centres of the brain.

Franck speaks of them as psycho-motor centres, because they control by their psychical influence the true motor apparatus. He says that "in examining the movements produced by the excitation of points under the control of the cerebral cortex, they may be regarded as analogous to reflex movements; but the essential difference between the movements so started and the ordinary reflexes consists in the point of departure of the original impulse. In one case it is cerebral, in the other cutaneous, but in every case it is peripheral in relation to the centre of motion (medullary centres)." Strictly speaking, then, the pyramidal tracts transmit *afferent*, and not *efferent*, impulses to the motor cells of the cord and medulla. Marique adopts somewhat this reflex theory for the motor centres; for he found that simple separation of the motor from the sensory areas, as a result of cutting the associating fibres, produced the same form of paralysis as when

[1] Philadelphia Medical Times, December 18, 1880.

the cortical motor areas themselves were removed. He concludes, therefore, that the motor areas cannot act of themselves, but that, functionally, they are dependent upon impulses transmitted from the sensory areas of the parieto-occipital region. This question is far from being settled, however, since such varying results have been obtained in the experiments of Franck and Pitres, Marique, Vareth, Exner, and Paneth.

According to M. Soury, Lisso has collected, since 1882, some eighty-eight cases in which disturbance of sensation accompanied cortical lesions of the motor area. Hence Tripier and Gilbert Ballet have named the cortical area the "sensitive-motor zone." Exner admits that the different areas for tactile sensibility of the various parts of the body are intermingled with the motor areas. In his study of aphasia[1] Dejerine says: "These disturbances of cutaneous sensibility accompany the beginning of the paralysis itself in the majority of cases, sometimes they even precede the latter. These phenomena are not rare in the course of a hemiplegia of cortical origin, and they deserve close study." The lesion in the case of Dejerine was limited exclusively to the motor cortex, leaving the sensory paths intact. Dupuy notes that Horsley reported to the Congress of Brighton, in 1886, that the removal of a part of the motor cortex in three patients, for epileptiform seizures symptomatic of cortical lesions, resulted in the partial or complete loss of sensibility. Seguin[2] and Weir reported the case of a man, aged thirty nine, who complained in the autumn of 1882 of severe head pain and convulsive attacks, limited to the right side of the neck and face. From 1885 these attacks occurred very frequently and were associated with a sensation of cold. The spasms involved the right arm and hand as well as the face. Finally paresis supervened in these parts, and was accompanied by aphasia and agraphia. The diagnosis was tumor in the facial centre of the left motor zone. Operation proved it to be a sarcoma, about an inch in

[1] Revue de Med., 1885. [2] Soc. de Biol., October 30, 1886.

thickness, nesting beneath the foot of the second frontal and the anterior border of the ascending frontal convolutions. A report of the case in the *Journal of Mental and Nervous Disease*, of December, 1888, one year after the operation, states that there was unquestionably anæsthesia of the cheek, hand, and forearm to contact tests as well as with the æsthesiometer. There was also anæsthesia of the lower part of the face, lips, and inside of the cheek. From the study of the sensory tracts and of a series of American cases of cortical lesions, Starr [1] concluded that the motor and sensory areas coincided, though the former extended beyond the latter, and included the postero-parietal lobe as well as the Rolandic region. Four of the cases in Starr's list belonged to Mills, and in reviewing his notes the latter came to the conclusion that they at least did not support the inference drawn by Starr. From a careful review of one hundred and thirty-seven cases, Dana [2] decided that the sensory (tactile sensation) and motor areas were coextensive. In the discussion of Dana's paper Starr and Seguin argued with the author, but Mills favored the doctrine of Ferrier, namely, that the centre for tactile impressions was to be found in the gyrus fornicatus, and gyrus hippocampi. Stricker maintains that motion and sensation are so intimately related as to be almost identical. His views can be most clearly portrayed by an illustration. When one represents to himself, for instance, the movements of a cloud, the muscles of the eyes undergo the same sort of a sensation as though they were actually gazing at a moving cloud. By checking this muscular sensation within the eyes, the mental image of the cloud immediately ceases its movement. The cloud seems absolutely stationary.

Among the Italians Lussana and Lemoigne maintain that there are sensory and motor areas in the cerebral hemispheres, but that they do not act upon one another

[1] Journal of Nervous and Mental Disease, New York, July, 1884.
[2] Ibid., October, 1889.

in the manner of a simple reflex. Tamburini, Luciani, and Seppilli have elaborated, since 1876, the theory that the "motor zone" consists, on the one hand, of the centres for cutaneous and muscular sensibility, and on the other, of the centres for motor ideations. This, as will be recognized, is a very elaborate, mixed, and comprehensive theory. It well illustrates, says M. Soury, the eclectic tendencies of the Italian school. As a general rule the Italians are as much opposed to the views of Hitzig and Nothnagel as they are to those of Schiff and Goltz. They incline somewhat to the theories of Ferrier and his English followers. In other words, they believe that the paralysis caused by injury of the cortical motor areas, pathological or experimental, is neither ataxic nor reflex. It is distinctly and entirely a paralysis in the truest sense of the word. Such at least is the opinion of Albertoni and Michieli, Lussana and Lemoigne, Tamburini, Luciani, Seppilli, Maragliano, Bianchi, Palmerini, Tonnini, and others. In the words of Maragliano, all motor phenomena should be regarded "as dependent upon true voluntary motor centres, which are capable, without the intermediation of any other motor centres, of starting into activity the muscular apparatus of the body." Equally clear in their statements are Luciani and Tamburini. These authors, unlike Ferrier, localize even the centres of voluntary motion in the basal ganglia, particularly in the corpora striata. Injury to these ganglia, as well as to the corresponding centres of the cortex, does not result in ataxia or the phenomena of inco-ordination; nor is any alteration of general sensation, including the sense of touch, to be detected in animals whose motor zones have been operated upon. The striate body, it will be remembered, is, according to Ferrier, the centre for movements which once were voluntary, but which afterward have become automatic. Thus a dog can still run and swim if the striate body remains intact, though the corresponding cortical areas have been removed. Luciani and Tamburini endow the basal gan-

glia with the same psychic functions as the cortical areas, and thus differ considerably from Ferrier. They speak of them as psycho-motor centres, probably meaning thereby that the basal ganglia, as well as the cortical motor centres, are in direct connection with the sensory centres. "The basal ganglia," they say, "and especially the corpora striata, possess the same physiological value as the centres of voluntary motion, or, in other words, these centres can be put into action directly by psycho-sensitive sensorial processes." When the authors promulgated these ideas, it was supposed that the function of the striate bodies was motor; now, however, it is known that the hemiplegias due to hemorrhage in this region are the result of the injury done to the internal capsule. In fact the striate bodies have been completely transformed into cysts, and yet there was no paralysis so long as the internal capsule continued intact. Hence these earlier views of Luciani and Tamburini are now quite untenable; nevertheless it must be admitted that the recent study of the striate bodies (caudate nuclei) by Baginsky and Lehmann seems to reveal some truth in the earlier views of these Italian authors.

The so-called paralysis, resulting from a destructive lesion of the excitable zone of the cerebral cortex is believed by some of the Italian writers to be due entirely to the loss of sensation. Silvio Venturi,[1] of Padua, adopted this ataxic theory in 1878. It was Schiff, the distinguished predecessor of Luciani in the chair of physiology at Florence, who became the chief exponent of this sensory explanation of the paralysis. In 1871, the year after the experiments of Fritsch and Hitzig, the editor of *l'Imparziale Medico*, inspired by Schiff, wrote that all the immediate effects of injury to the so-called motor centres of Hitzig were really the result of a disturbance of sensibility and were limited entirely to that sphere. In several Florentine publications, issued in 1873 and 1876, Schiff recalls these facts. According to

[1] Arch. Ital. per le mal. nerv. 1878.

this physiologist, a dog with a cerebral lesion is not affected with any loss of energy in the muscles of the opposite half of the body, but merely with an absence of the feeling of surety and power of adjustment in its various movements because of the loss of tactile sensibility. The general movements of running and leaping are all well performed, but there are marked evidences of an uncertainty in regard to the position of the limbs. This anæsthesia is entirely cutaneous, according to Schiff, while the sensibility to pain and pressure remains undisturbed. Alternations of the sense of pressure and temperature are caused by the increased depth of the cerebral mutilations. While these views, together with the experiments of Schiff, are not accepted by the majority of physiologists, they have very greatly modified the original theories of many of them in regard to the motor character of the so-called motor areas. Hitzig himself, who was so vigorous a supporter of the purely motor theory, has altered his conceptions to such an extent as to refer to these motor phenomena under the name of disorders of the muscular conscience. Schiff's theory is that of a pure reflex. An impulse from the periphery, for instance, is sent inward to the brain, and there, within some hitherto undiscovered subcortical centres, is transmuted into an efferent impulse, which is sent out again to the muscular apparatus. This cerebral reflex, he insists, is similar to the spinal reflex, and the phenomena due to its disturbance are similar to the reflex phenomena due to injury of the posterior columns of the cord. It should be noted that Schiff locates the reflex centres not in the cortex itself, but somewhere beneath the cortex. There have been many objections and objectors to these views of Schiff, and his followers form quite a small minority. But it must be admitted that, like his opponent Hitzig, he has done valuable service to the science of cerebral localization, for if Hitzig discovered the results of injury to the motor areas of the cortex, Schiff revealed those due to injury of the centres for tactile sensation. To judge

from the doctrines of Munk, Luciani, and Seppilli, the future will have to acknowledge Schiff, as well as Hitzig, as one of its forerunners. When Schiff asserts that "one thing is positive, there are no cortical centres,"[1] we are somehow forcibly reminded of Goltz. Though Schiff can enumerate many objectors, chiefly among the followers of Ferrier, such as Lussana, Tamburini, Bechterew, and Horsley, his teachings, like those of Goltz, have acted as a wholesome check upon the too rapid assumption that all movements of the body originate from certain limited areas of the cerebral cortex. They have induced experimenters to study somewhat more minutely the character of all muscular movements, the relation of the centres for these movements to the centres for sensation, and the influence, if there be any, of the higher mental faculties, the purely psychic functions of the brain. The extremely difficult and complicated nature of the problems involved taxes the keenest powers of the psychologist as well as of the physiologist.

Tamburini has attempted a reconciliation of the two opposing views just noted. He admits it is probable that the points of the cortex where the inpouring sensory impulses are transformed into outgoing motor impulses correspond identically with the cortical areas upon which so much study has been expended. In his own words, "each of these centres may be at the same time the focus for the reception and perception of the sensory excitations sent inward from a given part of the body, and the point of departure for the voluntary centrifugal impulse going to the muscles of the same part." This, he believes, explains the absence of sensibility in the direct production of localized movements; for in the one instance the electric current takes the place of the nervous current or impulse, and in the other the removal of the cortical centres must necessarily abolish the perception of the peripheral impressions. In conjunction with Luciani, Tamburini has extended this same theory, in regard

[1] Pfluger's Arch. f. Physiol., xxx., 253.

to the excito-motor zone of the cortex, to the centres for sight and hearing. The movements of the ear and eyeball, initiated by a sensory impression at the periphery, are not of the nature of a pure reflex, as Ferrier believes, but simply the result of the intermingling of the corresponding sensory and motor cells of the cortex. In other words, corresponding sensory and motor cells lie in close juxtaposition within the various cortical areas. These views of Tamburini seem to be supported by an anatomical as well as physiological basis; for, as I have already pointed out, the region of the hippocampus major, which Ferrier and his followers assert is sensory in function, contains a row of large pyramidal cells between the medullary centre and the so-called stratum radiatum; and these cells are identical, so far as their microscopical appearances are concerned, with the supposed motor cells of the central convolutions and of the anterior horns of the cord.

In 1880 Luciani, who, like Seppilli, found that the effects of a circumscribed lesion within the motor areas of the cortex were not only paralysis or paresis, but also an alteration of the muscular and cutaneous sensibility more or less pronounced, wrote that "the motor centres and the sensory centres, which together perform a very complex function, are intermingled, or lie in the closest proximity (*in gran vicinanza*) within the cerebral cortex." He verified the phenomena described by Munk, but he did not look upon the paralysis as psychical in character; that is, as the result of the loss of mere sensation of mental images or of psychic representations. It was purely organic and depended directly upon the injury to the motor cells, just as the disturbed sensibility depended upon the injury to the neighboring sensory elements. The motor centres, therefore, like the centres for sight and hearing, were of a complex nature, and in reality sensori-motor. Luciani says, "The motor centres are not localized within the cortical area called up to the present time 'the motor zone,' a name which we must hereafter

abandon, since this zone is not exclusively motor. All the different regions of the cortex are more or less strewn with special motor centres. In order to be positive of having destroyed all the motor centres, one must remove the entire cerebral cortex." This is a remarkable statement of a singularly comprehensive theory, and leads us back once more to the vigorous discussions of Goltz.

Danillo has demonstrated that when the occipital lobe —which is supposed to be entirely sensory in function—is stimulated, the movements of the eyes are not simply reflex, as Ferrier taught, because they are still observed when, after the ablation of the entire cortex of the occipital lobe, the underlying white substance is electrically excited. In this white substance, therefore, there must be motor fibres springing directly from the cortex of the occipital lobe, unless we imagine that these same fibres go to the central lobules, and through them, rather than directly, transmit the motor impulse to the muscles of the eye. Even such a conception, however, would represent the process within the occipital cortex as reflective, but the outgoing impulse in such a case would be transmitted into an ordinary motor one before it finally reached the eye muscles. This difficulty might have been solved by removing, as Goltz has done, the entire cerebral cortex except that of the occipital lobe, then exciting the latter, and noting whether there were any movements of the eyes. I do not know whether such an experiment has been performed, but it is one which, if possible, is greatly to be desired. In fact, each of the sensory areas should be thus isolated, excited, and the effects closely studied in regard to the production of any motor phenomena. Since the distinguished physiologist of Strasburg has succeeded in removing vast amounts of brain-substance without destroying the lives of the dogs, it would seem that such experiments as suggested would be quite feasible. Bechterew has accomplished this to a certain extent, and finds that when the so-called motor areas of the central lobules are separated from the occipital centres, stimulation of

the latter still gives the same muscular response. He argues, furthermore, that the movements of these muscles cannot possibly be of the nature of a simple reflex, because they are always uniform and localized within the same group. Stimulation of the occipital cortex excites motor points, therefore, that do not belong to the so-called motor zone, whose fibres pass only through the pyramidal fasciculi of the cord. These mixed centres being situated thus outside of the cortical areas to which the pyramidal fasciculi run, require for their excitation a much stronger and longer current; their destruction does not involve manifest disturbances of motion; and the movements which they give rise to are not very clearly differentiated from those caused by excitation of the true motor zone. Bechterew argues, therefore, that the sensory areas do contain motor centres, or at least motor elements, and he accounts for the fact of their stimulation requiring a stronger current and one longer in duration, on the ground that they do not connect with their corresponding muscles through the intermediation of the anterior roots of the spinal cord, but through certain masses of gray matter situated deeply within the cerebral hemispheres, probably the optic thalami. According to Bechterew, then, there are two sorts of motor centres within the cerebral cortex. One variety is easily excitable and found in the central convolutions; the other is not so easily excited, and is scattered in among the sensory centres. This author bases his views chiefly upon his experiments on new-born animals, in which the movements of the ear and the conjugate movements of the eyes, for instance, can only be produced by direct stimulation of the corresponding areas of the cortex, one week and one month, respectively, after the movements of the limbs have been elicited by excitation of the central convolutions.

We have thus seen that the sensory areas of the cortex do contain motor elements, and that in all probability they exercise some special influence upon the associated muscular apparatus. From our rapid review of the mod-

ern theories among the English and German physiologists, we note that there is a growing tendency to believe that the motor centres of the central convolutions have sensory elements intermingled with them.

Luys [1] remarks that certain convolutions are distended and hypertrophied when certain cerebral symptoms have been present. In cases of delirium with delusions and hallucinations, he found a pronounced gibbosity of the paracentral lobule, to which is usually assigned a strictly motor function. It is unfortunate that no mention is made as to whether the delusions and hallucinations partook of the motor more than of the sensory type, whether they were mental representations of abnormal kinesis or æsthesis. They seem to show, at all events, that the cortical areas, both motor and sensory, are ideational and psychic, psycho-motor and psycho-sensory, rather than simply organic. Mickle [2] has shown that hallucinations are due mostly to lesions of the sensory centres of the brain. Thus lesions of the angular gyrus produce visual, and of the temporal gyrus auditory, hallucinations, but not to the full extent that one would have been justified in anticipating. This shows, therefore, that sight and hearing are not dependent upon these centres solely.

The centres of general sensation, by which we mean those for touch, pain, and temperature, are usually located just back of the motor centres in the parietal lobe, between the calloso-marginal, parieto-occipital, and retro-central fissures. These are less clearly differentiated than the corresponding motor centres. It is possible that our ignorance in this respect is due to the general unreliability of sensory as compared with motor symptoms, and the difficulty which we experience in deciding always the exact nature of a certain symptom, which may be in fact purely sensory, but which by reason of the pain, restless discomfort, and reflex phenomena, unavoidably gives rise to abnormal movements and other motor appear-

[1] Le Progrès Médical, 1889.

[2] Jour. Ment. Science, October, 1881, January and April, 1882.

ances. The cells of the sensory areas are pre-eminently receptive, and neither physiological experiment nor clinico-pathological observation has yet proved that they are in any way directly emissive. There can be little doubt but that they are connected with the motor cells of the cortex, and transmit special impulses to the latter. These two sets of cells, thus intimately united, form the summit or bend, as it were, of the arch about which the sensori-motor impulses travel, and are therefore in all likelihood the true physical basis of mind. The gross character of the general sensibility and of the movements of the body, as compared with that of the organs of special sense, necessitates the corresponding sensori-motor ideational centres of the cortex being so much more developed than the centres for the special senses. In connection with the sight and hearing, the proof is pretty conclusive that sensory and motor cells lie in close juxtaposition, and are most intimately conected by associating fibres. We infer that the same ideational centres cap the arches about which play the afferent and efferent impulses from the eye and ear. Hence I take it that the cerebral cortex is, after all, only a grand reflex centre. It is far more delicately organized and specialized, however, than the reflex centres of the cord, but in all other respects it is quite comparable to the latter.

The morphological and embryological development of the brain throws a flood of light upon the relations of its motor and sensory elements with each other. Among the invertebrates there is no brain or spinal cord such as we find among the higher orders of animals; nevertheless the spinal cord of the latter is clearly foreshadowed in the single series of sensori-motor ganglia, with their projecting nerves, found in the respective segments of the invertebrate. In the articulata and insecta we know that each segment is furnished with a little brain of its own, which is nothing more nor less than the summit of the reflex arc for that particular segment; and we furthermore know that the little brain of the most forward seg-

ment of the creature is but a ganglionic development of the cord, comparable to the various ganglia of the other segments. This is illustrated beautifully in the anatomy of the worms and insects. In some of the higher representatives of these orders the ganglia of the most anterior part of the body become massed together, undergo a somewhat fuller development to subserve the purposes of certain special sense-organs, and so in a measure assume the characteristics of the brain of the vertebrates. Note as illustrative of this the exquisite arrangement of the nervous system of the white ant (Termes), the fly (Musca), and the scorpion spider (Thelyphonus caudatus). In all of these creatures the various segmental ganglia are connected with each other like the cells making up the circuit of an electric battery; and some of them are so far advanced in development as to simulate, without representing, the brain and spinal cord of the higher mammals As we proceed up the scale of evolutionary advancement we behold the nervous system becoming more and more complicated and specialized, assuming more and more the nature of the primate brain and spinal cord. In the vertebrates, and even their highest representatives, man and the apes, the primitive invertebrate appearance of the cerebro-spinal axis is not wholly lost. As Owen says, a vertebrate is but a clothed sum of segments, and therefore nothing more nor less than a higher invertebrate. In the lowest vertebrate, the *amphioxus lanceolatus*, there is only a spinal cord without a brain, and in all its habits this creature closely resembles the invertebrates. The peculiar character of the vertebrate skull, which is now admitted to be composed of metamorphosed vertebræ, the embryological development of the brain and spinal cord from the same germ-layer, and the similarity of the brain and cord up to a certain point, are all extremely indicative of the primitive characteristics of the encephalon of man. It seems to me that, if there be any truth whatever in the principle of evolution, it is not irrational to look upon the brain of the vertebrate as a highly devel-

oped portion of the spinal marrow, or of the ganglia of the spinal cord lying most frontad. If such be the case, we would expect some similarity between the arrangement of the sensori motor elements of the brain and those of the vertebral segments of the spinal cord. The motor cells would not be identical with, but rather lie in close proximity and intimate relationship with their corresponding sensory cells. The extreme simplicity of this arrangement in the cord is, of course, quite obliterated by the overcrowding of so vast a number of nervous elements in so confined a space as the cranium. In this, however, we see somewhat a confirmation of the doctrine that the brain is a composite rather than a simple organ. The rolling about of the encephalic ganglia during their embryological and evolutionary development, in order to accommodate themselves to the constrained limits of the interior of the skull, results in a disappearance of that relative and simple arrangement of the sensory and motor elements which we see in the vertebral segments of the spinal cord. Nevertheless, the actual arrangement is even still such that we can faintly distinguish the resemblance to the spinal arrangement; we can recognize the fact that the ganglia and cortex of the brain are like the summit of the sensori-motor reflex arc as we find it more clearly presented in the cornual sensori-motor arcs of the spinal segments. In the brain it is seen, for instance, in the relative arrangement and mutual development of the cortical motor and sensory areas. General sensation is the least specialized of the sensory functions of man, and being co-extensive with the entire surface of the body proves man's connection with the lower animals. The corresponding development, the similarity in extent, and the relative antero-posterior location of the cortical sensory and motor areas, reveal their connection with similarly related parts of the body, and their similarity with the sensori-motor arcs of the spinal cord. Their excessive development in size and function gives them a preponderance over the corresponding segments of the cord,

and in their function, especially, makes them appear as though they were voluntary, while the latter were involuntary. But voluntary and involuntary are relative terms, expressing different degrees of the same form of nervous activity. The psychic functions of the cerebral cortex are involuntary quite as much, if not in so glaring a manner, as the involuntary functions of the various segments of the cord. They are both alike a form of reflex action, but instead of the cerebral reflexes being direct and unconscious as they are in the cord, the more sensitively and highly organized character of the cortex causes them to assume the character of consciousness and self-will, while the connection of the cortex with the segments of the cord, as these in turn are again connected with one another, causes the cortical reflexes to be transmitted and perceived through the medium of the spinal centres rather than directly from the periphery of the body. In regard to the special senses of sight and hearing, the reflex sensori-motor arc does not pass through the cord or its ganglia, but is limited solely to the encephalic ganglia, while their sensory elements are always posterior to, and more or less in close proximity with, the motor elements, just as they are in the spinal segments.

The bi-lateral character of the spinal cord functions is duplicated in those of the encephalon.

At the session of the Société de Biologie of Paris, May 25, 1889, M. Dupuy reported a case showing the identity of the two hemispheres of the brain in regard to their functions. The patient possessed the power of moving the two eyes in different directions at the same time. Even the perceptive centres were distinct, despite the opinion of Horsley to the contrary, for the young woman saw objects with one eye, and when she tried to use both eyes together to view the same object she was overcome with dizziness. Magnan [1] has had four cases of this sort, one of which he reported in full. The patient heard one class of statements in one ear and another in the oppo-

[1] Journal de Méd. de Bordeaux, September 30, 1883.

site ear. Agreeable ideas only were received on one side of the head, disagreeable ones on the other. Brown-Séquard long ago insisted upon, and physiologists are now beginning to recognize, the fact that the two hemispheres have identical functions. Hence I conclude that man's mental activity is largely automatic and reflective; that the cortical centres for ideation are constituted, related, and localized, with respect to one another, much like the reflex centres of the spinal cord, but that the finer development of the former gives them a finer degree of activity; that the sensory and motor elements of the cortex are not identically the same, but are separate, closely intermingled, and intimately connected with one another; and that an explanation is thus afforded of the simultaneous appearance of the two sets of symptoms, motor and sensory, in corresponding parts, when an irritative or destructive lesion is limited entirely to one or the other of the associated cortical areas.

If this progressive differentiation of function, based upon the principle of reflex action, continues within the encephalon as it has up to the present time in the evolutionary development of the nervous system of animals, it may ultimately happen that the mind will be capable of thinking upon two or more subjects at one and the same moment. Its capabilities will thereby be immensely enhanced, and the old dictum of the psychologists, that the association of two or more ideas is always consecutive, never coincident, will be overthrown. In his paper upon the "Molecular Dynamics of the Encephalon," published in the *American Journal of Insanity* for October, 1889, Dr. Williams has hinted at this future possibility. "Who knows," he asks, "but that the more fully evolved mind of the future shall learn, after the present mind has come to look with stunned discouragement upon the vast field of knowledge presented to its view by an advanced civilization, gradually to so adjust its fibres and its vessels by isolating them into separate fields momentarily (since the isolation is the acme aimed at by the higher mind in

its concentrated workings to-day), that consciousness may, in fact, come to be not a single energy but a double, triple, quadruple, or multiple energy? Imagine, for example, the school boy of the thirtieth century studying his mathematics visually with concentration, while orally listening to a lecture on a different topic. In all seriousness, there seem to be some reasons for believing that such a seemingly paradoxical mentality may be evolved." The tendency of mental development is certainly in this direction. It is already so striking a characteristic of the human mind as to place man infinitely above the lower animals. The separation of the various representative areas of the cortex, so that even now an animal can feel a prick in the foot, move his paw, and listen attentively to some unwonted sound all at the same moment, would seem to give promise of such a desirable future possibility.

A mere glance at the localization of the various centres of the cerebro-spinal apparatus, when compared with their relative functions, favors the view of the similarity of the brain and cord in regard to their primitive structure, and of the more ancient and higher development, both anatomically and physiologically, of the forward part of this nervous apparatus. When closely studied, it appears that inhibition is the highest function of all nervous matter. To inhibit an action presupposes a finer degree of development on the part of a nervous centre than merely to receive and transmit a reflex impulse. Inhibition is the real nature of mind, and is of so startling a character as to give the impression of absolute independence resulting in free will. The inhibitory function of the mind is admitted by all physiologists and psychologists, while the former assert that, were it not for this magnificent function of the highest of all the cerebral centres, our bodies would be kept in a constant state of convulsion through the manifold impulses which our nervous systems receive and reflect outward again to the muscles. Mills speaks of the higher psychical cen-

tres in the fore-brain as constituting the "inhibitory lobe." When we remember that all mentalization is based upon sensory and motor phenomena, and that the cortical areas for the psychical representation of these phenomena are quite definitely outlined, we are not surprised that there should be so much mystery surrounding the functions of the unknown areas of the brain. We note that injuries of the pre-frontal lobes result always in mental deterioration with abnormal psychical phenomena, while it is generally admitted by the best physiologists that one function of this *terra incognita* of the cerebral cortex is at least inhibition. Putting all facts and inferences together, then, we may safely conclude that the power of inhibition is the last of the acquired functions and the special characteristic of the most highly organized nervous matter; that this power resides in the gray matter of the pre-frontal lobes to a very high degree; and that therefore they are pre-eminently the psychical centres irrespective of the mind, being the result of the combined activity of all the sensori-motor elements of the cortex. And we furthermore infer that this anterior, highly specialized portion of the brain, differs from the rest of the nervous apparatus in structure and function in degree rather than kind. I take it, therefore, that all inhibitory centres are higher in development than the centres which they inhibit.

In the organic evolutionary progress of the animal the centres of the medulla that preside over the vital processes may be the oldest in time. They are first because they are necessary for life itself, but in the physical development of the animal there are centres which precede these in importance, and if, as the biologists tell us, the more highly organized matter is the most ancient, these important physical centres may, after all, be the oldest in time, while the centres of the medulla may be simply later differentiations of nervous matter set apart for the special regulation of the vital processes. It is probable, therefore, that the highly specialized, inhibitory, psychical

centres of the fore-brain are the most primitive portions of the nervous apparatus, so far as the evolutionary development of nervous matter goes; though from the embryological stand-point the cord is the primitive factor. In its influence upon the next lower centres, namely, the so-called sensory and motor areas of the brain, the fore-brain is comparable to the latter in their inhibitory influence upon the centres of the medulla and spinal cord. The inhibitory function is thus graduated from the highest psychical centres of the fore-brain down to the lowest organic centres of the cord, where it is practically so overpowered by the inhibitory influence of the higher centres that it appears entirely absent, permitting the cord to act only as a gross and unobstructed reflex centre. In its evolution, therefore, the whole cerebro-spinal axis seems to be but a series of connected sensori-motor ganglia or reflex couplets differing in different parts more in degree than in kind.

Even in the relative positions of the various subcentres of the motor area of the cortex, there can be recognized a certain correspondence with the associated parts of the body, if it be remembered that the head of man is bent sharply forward to accommodate it to the erect position of the body. In like manner with the corresponding parts of the body, the centres of the cortex follow one another from front to back in the order of the head, arms, trunk, and legs. This is illustrated otherwise in the fact, as pointed out by Horsley,[1] that the variation in the representation of motor functions is more marked as the motor area is traversed from above downward than from before backward. In other words, by carrying the faradic stimulus backward over the cortical motor area, the parts of the body affected follow more naturally in the regular order than if the same stimulus were carried over the same cortical area from above downward. The relative smallness of the representative area for the trunk muscles, as compared with that for the extremities, has

[1] American Journal of the Medical Sciences, April, 1887.

been well accounted for by Mills, on the ground that the movements of the trunk are simply subordinate to the purposive movements of the limbs, and hence require only a comparatively small part of the cortex for their primary representation.

In summing up, then, I would offer the following propositions :

1. The motor and sensory areas of the cortex are not sharply distinguishable from one another, as was at first supposed by Ferrier and his followers.

2. Nor are they, as separate areas, of such character and unimportance as to render the action of the brain practically that of a uniform single organ, for which Goltz and his school contended.

3. There are separate motor and sensory centres within the cortex, but they are closely intermingled and most intimately connected with one another.

4. Both the motor and sensory areas have foci of special intensity ; the former in the central, the latter in the postero-parietal, lobules.

5. While there may be a general inter-communication between all the sensory and motor elements of the cortex, there is the most intimate connection between the related sensory and motor cells that preside over corresponding parts of the body.

6. The primary function of these cortical sensori-motor groups of cells as couplets is reflective, like that of the sensori-motor reflex arcs of the various spinal-cord segments. This is shown by the morphological and embryological development of the cerebro-spinal axis ; and it explains most satisfactorily the majority of the sensori-motor phenomena of physiological experiment and clinico-pathological observation.

7. Mentalization and thought itself are dependent upon sensori-motor phenomena, so that there is a strong probability that mind itself is the product of the activity of the entire cortex.

8. The power of inhibition is apparently the latest and

highest differentiation of the functions of nervous matter, though it is itself a latent function of all nervous substance, varying in degree merely with the stage of the latter's development.

9. Inhibition is the special function of the fore-brain, and therefore endows this part of the nervous system with a commanding influence over the rest of the nervous apparatus. The fore-brain is therefore pre-eminently the psychic centre, though when exhaustively analyzed its inhibitory and reflex functions differ from the inhibitory and reflex functions of the ganglia lower down in the cerebro-spinal axis, in degree rather than in kind.

10. The sensori-motor functions of the cerebral cortex are psychical in character, and influence the external parts of the body only through the mediation of the cord and special ganglia, just as the highest of all the psychic centres, the fore-brain, influences the body through all the sensori motor centres of the cortex, special ganglia, and spinal cord.

11. In fine, inhibition and reflex action being the special property of all nervous matter, they are found in varying gradation as the functions of the most highly organized matter of the fore-brain, which therefore seems to be the special seat of mentalization, down to the most primitive ganglia of the spinal cord, which retain only the lowest degree of reflex irritability.

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